Mine Burial Prediction: A Cooperative NRL/ONR Study

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LONG-TERM GOALS

Development of an accurate, real-time, mine burial prediction capability by field testing and validation of an integrated, physics-based, mine burial model.

OBJECTIVES

Sediment-structure interactions are responsible for the burial/penetration of heavy objects, such as bottom mines, pipelines, concrete breakwaters, and offshore platforms in the seafloor. On seabeds of low shear strength mud, these objects are known to penetrate on impact when the bearing capacity of the seafloor is exceeded, with additional subsequent burial from sediment consolidation and creep. On sand seabeds, burial is common by scour and fill, momentary or cyclic wave-induced liquefaction, and seabed morphological changes (e.g., transverse bedform migration, changes in shore-rise and bar-berm conditions, sediment deposition). Using a field experimental approach, the Naval Research Laboratory (NRL) will test and evaluate physics-based mine burial processes and models in order to provide the US Navy with an accurate, real-time mine burial prediction capability.

APPROACH

NRL is tasked with development, deployment, and analyses of data from instrumented mines; conducting of impact and subsequent burial experiments; development of an improved impact burial model; and development of an integrated mine burial model. One of the major problems in the experimental validation of mine burial models is the difficulty of continuous measurement of the behavior of the mine. An optically instrumented, cylindrical, subsequent burial mine, developed by NRL, provided a tool for continuous monitoring of the movement of the mine (heading, pitch and roll), as well as the percentage of the surface area actually buried (Richardson et al., 2001; Griffin et al., 2001; Richardson and Traykovski, 2002). The next generation, acoustically instrumented, subsequent burial mines were developed by OMNI Technologies Inc. under the direction of NRL as part of a Small Business Innovative Research initiative and have the potential to extend that monitoring capability to characterize developing scour pits, migrating sand dunes or ripples; quantify the boundary layer flow around the mine; measure sediment concentrations and flux in the vicinity of the mine; measure sea state and bottom currents; determine initiation of bed load transport; and calculate sediment transport (Griffin et al., 2002; see Griffin et al., this CD). An instrumented, cylindrical, impact burial mine was developed for impact burial experiments and is capable of monitoring mine

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motion during free-fall across the air-water interface, through the water column, and into the seabed sediments (three accelerations and three angular velocities) (Valent et al., 2001, 2002).

NRL leads the effort to improve the Impact Burial Prediction Model (IBPM) using data collected in tank and field tests during FY01-03 and is responsible for improving and validating the sediment penetration module and for integrating a hydrodynamic module and stochastic relevance into a final impact burial model. Field experiments on burial by scour and fill; bedform migration; bedform morphological alterations; liquefaction or fluidization of the sediment; and biological processes were conducted in the winter of 2002-3 off Tampa Bay and are scheduled for the Martha's Vineyard Coastal Observatory (MVCO) during the winter of 2003-4. For all these experiments, NRL is responsible for: (a) deployment and analyses of data from instrumented mines, (b) quantification of environmental processes in the near field of the mine, and (c) characterization of mine movement and burial. These data will allow development and validation of new and proposed mine burial models.

Advances in our physical understanding of mine burial and the new mine burial models resulting from these joint experiments, including NRL modifications to the impact burial model, will be integrated into a framework for a stochastic approach to mine burial prediction. This model recognizes that mine or object burial is time dependent, spatially and temporally variable and that burial processes are not independent (Richardson et al., 2001). The integrated mine burial model will require as input: (a) wave climate and tidal and storm-induced bottom currents from in situ measurements or numerical oceanographic models, (b) sediment physical properties and small-scale morphological feature description from in situ measurements or historical databases, and (c) description of the anticipated mine threat. The model (preliminary version completed in 2003) will provide both strategic and tactical mine burial prediction. NRL will also assess the effects of uncertainties in the input parameters for predictions of mine burial at impact and by subsequent burial through stochastic simulations involving most free parameters. This differs from a sensitivity analysis where typically the effect of one variable is found throughout its variation. With stochastic simulations, all variables can vary and the model's convolution of the uncertainty through its nonlinearity can be addressed.

WORK COMPLETED AND RESULTS

Impact Burial Experiments: Impact burial experiments were conducted during May 2002 along the Texas continental shelf near Corpus Christi, Texas and June 2003 on the delta of the Mississippi River (58 impact burial data sets to date). NRL provided diver support for the experiments, collected gravity cores for subsequent ship-board and laboratory analyses of sediment physical properties, measured in situ shear strength with STING and XBP penetrometers, and deployed the instrumented impact burial mine. The motion of the mine, from the moment of deployment through embedment in the seafloor, was characterized using data collected from the 3-axis fiberoptic gyro (roll, pitch and heading) and 3-axis accelerometers and magnetometer (movement through space - x,y,z) within the instrumented mine. NRL developed software to analyze this complex motion (Theophanis et al., submitted). Much of the mine motion data was given to ONR modelers (see paper by Kim et al., submitted) and the remainder will be disseminated when quality control of the data is complete. Sediment cores have been logged (sound speed, attenuation and bulk density) at NRL and Texas A&M University laboratory facilities; opened for visual inspection; shear strength measured with a motorized laboratory vane; and subsamples collected for analyses of sediment porosity (equivalent to water content and void ratio), grain and bulk density, and grain size distribution. These values of sediment physical and geotechnical properties, together with the 6-degrees of motion of the mine will be used to evaluate predictions of the

current impact burial model (IBPM28). During FY04 the laboratory work will be completed, data summarized, mine trajectories calculated and all data provided to ONR scientists. Based on the results of these experiments a final impact burial experiment is planned for May 2004 off the mouth of the Mississippi River.

To facilitate understanding the impact of the chaotic nature of the free-falling mine dynamics at the mudline on the performance and predictions of the impact burial model, the original code in QuickBASIC was rewritten in MATLAB. Final debugging and performance checks were performed by ONR Summer Research Intern Mr. Costin Barbu during his Summer 2003 work at NRL.

Subsequent Burial Experiments (MVCO, IRB): Subsequent burial experiments (ONR-MBP Program) were conducted in the shallow water area off Tampa Bay Florida (Winter 2002-3) and are planned for the WHOI Martha's Vineyard Observatory (Winter 2003-4). During FY03, NRL completed development and testing of the instrumented mines (with OMNI Technologies) used for those experiments. The original NRL optical mine was successfully deployed at the Martha's Vineyard Observatory three times during 2002-03. The mine was hard-wired (power and data transfer) using nodes provide by WHOI at 12-m water depth. Real-time burial data (mine movement and percent burial) was collected, as well as sector scan sonar images (1.3 MHz) of the mine burial process, and waves and currents using ADCPs and bottom mounted pressure sensors. The comparison of burial results to scour model predictions are very encouraging (Elmore and Richardson, 2003; Richardson and Traykovski, 2002). Mine burial studies at the Indian Rocks Beach site are in the preliminary stage of analysis. Mine movement (heading, roll and pitch) have been analyzed and pressure sensor data used to characterize tidal conditions, mine movement and surface gravity wave significant heights. Preliminary analysis of changes in percent burial (sensors covered) and scour pit development has also been made. Two or three significant burial events were recorded where mines pitched and rolled into the scour pit while changing heading with respect to ocean wave conditions. These events corresponded to the highest significant wave events and are generally in good agreement with real-time and post scour burial predictions. Preliminary results were presented at the Oceans 2003 conference in San Diego CA (Richardson et al., 2003).

Mine Burial Model Development: Development and validation of deterministic and stochastic mine burial models (including expert systems) are being carried out using NRL 6.2 core funding and are therefore beyond the scope of this proposal.

Data Dissemination and Publications: All ONR investigators will be provided with data from the instrumented mines and laboratory sediment characterization as soon as it is available (after quality control checks). Preliminary data for the subsequent burial experiments on mine burial and orientation has typically been made available within two months of the end of the deployment. Description of near field processes (mean and turbulent flow, sediment concentrations, and sediment transport) will take longer to analyze. It is hoped that other ONR investigators will participate in these analyses. Results of the 1/3rd scale mine; water column free-fall tests have been submitted for journal publication (Holland et al., 2003). Results of full-scale impact burial tests were published as a proceedings paper for the 5th International Symposium on Technology and the Mine Problem held in Monterey, CA (Valent et al., 2002), and in Oceans 2003 (Abelev et al., 2003). Results from the instrumented mine burial and sediment characterization will be made available on the ONR Mine Burial Web site. NRL will publish the results in peer-reviewed journals. Joint publications with other ONR investigators are encouraged.

IMPACT/APPLICATIONS

Buried mine detection has been and is still one of the greatest threats facing shallow water Mine CounterMeasures (MCM) operations. The possible presence of buried mines can change MCM tactics from mine hunting to minesweeping or area avoidance. The ability to predict mine burial both for planning and during operations (strategic and tactical scenarios) is therefore of great importance to Naval forces.

RELATED PROJECTS

All ONR projects in the Mine Burial Prediction Program (http://www.mbp.unh.edu/front/index.cfm).

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